CLAIMS

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1. A computer graphics system for processing image data including Z data for use in displaying three dimensional images on a display unit, comprising:

a depth buffer providing for temporary storage of Z data; and

a graphics processing unit having a graphics engine for generating image data including Z data, and a memory interface unit communicatively coupled to the graphics engine and communicatively coupled to the depth buffer via a depth buffer interface, the graphics processing unit being operative to compress at least a portion of the generated Z data, to write the compressed portion of Z data to the depth buffer via the depth buffer interface in a compressed format, to read portions of compressed Z data from the depth buffer via the depth buffer interface, and to decompress the compressed Z data read from the buffer;

whereby effective Z data bandwidth through the depth buffer interface is maximized in order to facilitate fast depth buffer access operations.

2. A computer graphics system as recited in claim 1 wherein the graphics processing unit is operative to compress selected ones of a plurality of tiles of the generated Z data based on a quantitative analysis of the Z data, each of the tiles of Z data having a plurality of pixels arranged in an array, each of the pixels being disposed at an associated (X,Y) coordinate of the array, and having an associated Z value.

3. A computer graphics system as recited in claim 2 wherein the graphics processing unit is operative to perform a process of compressing a tile of Z data, the process including a step of determining a plane based on the (X,Y) coordinates and associated Z values of selected ones of the pixels of the tile.

4. A computer graphics system as recited in claim 2 wherein the graphics processing unit is operative to perform a process of compressing a tile of Z data, the process comprising the steps of:

reading an anchor Z value associated with a selected anchor pixel of the tile;

reading a major horizontal Z value associated with a major horizontal pixel displaced a first predetermined number of pixels in a horizontal direction from the anchor pixel;

determining a major horizontal difference value between the anchor Z value and the major horizontal Z value;

determining a horizontal gradient value based on the horizontal difference value and the first predetermined number of pixels;

reading a major vertical Z value associated with a major vertical pixel displaced a second predetermined number of pixels in a vertical direction from the anchor pixel;

determining a major vertical difference value between the anchor Z value and the major vertical Z value;

determining a vertical gradient value based on the vertical difference value and the second predetermined number of pixels;

determining an ideal plane based on the anchor Z value, the horizontal gradient value, and the vertical gradient value;

for each of a plurality of remaining pixels of the tile, determining an associated ideal Z value lying in the ideal plane at the (X,Y) coordinate of the associated remaining pixel; and

for each of the remaining pixels, determining an associated minor Z difference value by determining a difference between the associated ideal Z value and the associated Z value.

5. A computer graphics system as recited in claim 4 wherein the process further comprises the steps of:

using the major horizontal difference value as a first major difference value in the compressed format;

using the major vertical difference value as a second major difference value in the compressed format; and

using the minor Z difference values as minor difference values in the compressed format.

6. A computer graphics system as recited in claim 4 wherein a compressed tile of Z data comprises:

a first portion of compressed Z data including the anchor Z value, the major vertical difference value, and the major horizontal difference value; and

a second portion of compressed Z data including at least one of the minor difference values.

7. A computer graphics system as recited in claim 4 wherein the graphics processing unit is further operative to perform the steps of:

determining if the horizontal difference value is greater than a predetermined maximum value; and

if the horizontal difference value is greater than the predetermined maximum value, writing the tile of Z data to the depth buffer via the depth buffer interface in an uncompressed format.

8. A computer graphics system as recited in claim 4 wherein the graphics processing unit is further operative to perform the steps of:

determining if the vertical difference value is greater than a predetermined maximum value; and

if the vertical difference value is greater than the predetermined maximum value, writing the tile of Z data to the depth buffer via the depth buffer interface in an uncompressed format.

9. A computer graphics system as recited in claim 4 wherein the graphics processing unit is further operative to perform the steps of:

determining if any of the associated minor Z difference values is greater than a predetermined maximum value; and

if any of the minor Z difference values is greater than a predetermined maximum value, writing the tile of Z data to the depth buffer via the depth buffer interface in an uncompressed format.

10. A computer graphics system as recited in claim 1 wherein the graphics engine comprises:

a plurality of graphics pipeline stages for generating image data including Z data; and

a Z raster operations unit communicatively coupled with the memory interface unit, the Z raster operations unit for receiving the generated Z data, and being operative to compress selected portions of the generated Z data, to receive compressed Z data from the depth buffer via

the memory unit interface and the depth buffer interface, and to decompress the compressed Z data.

11. A computer graphics system as recited in claim 10 wherein the Z raster operations unit is operative to perform read modify write operations including the steps of:

reading previous Z data from the depth buffer via the memory unit interface and the depth buffer interface;

merging the previous read Z data with associated portions of the generated Z data to provide merged Z data; and

writing the merged Z data to the depth buffer via the memory unit interface and the depth buffer interface.

12. A computer graphics system as recited in claim 10 wherein the Z raster operations unit is operative to perform read modify write operations including the steps of:

reading previous compressed Z data from the depth buffer via the memory unit interface and the depth buffer interface;

decompressing the read Z data;

merging the decompressed Z data with associated portions of the generated Z data to provide merged Z data; and

writing the merged Z data to the depth buffer via the memory unit interface and the depth buffer interface.

13. A computer graphics system as recited in claim 11 wherein the read modify write operations further include the steps of:

compressing the merged Z data; and

writing the merged Z data to the depth buffer via the memory unit interface and the depth buffer interface in a compressed format.

14. A computer graphics system as recited in claim 2 wherein the Z raster operations unit is operative to perform read modify write operations including the steps of:

reading a tile of previous Z data from the depth buffer via the memory unit interface and the depth buffer interface;

merging the previous read Z data with associated portions of the generated Z data to provide a tile of merged Z data;

determining if the tile of merged Z data may be compressed; and

if the merged Z data may be compressed, writing the tile of merged Z data to the depth buffer via the memory unit interface and the depth buffer interface in a compressed format.

15. A computer graphics system as recited in claim 2 wherein the Z raster operations unit comprises:

a read operation data accumulation unit for receiving the generated Z data, and being operative to accumulate portions of generated Z data associated with a current tile region, and to provide the accumulated Z data;

a decompression engine for receiving a previously written compressed tile of read Z data that is read from the Z buffer via the memory interface unit in a compressed format, the decompression engine being operative to decompress the previously written compressed tile to provide decompressed read Z data; and

a test unit for receiving the accumulated Z data and the decompressed read Z data, and being operative to compare portions of the accumulated Z data with portions of the decompressed read data, and being operative to provide selected Z data.

16. A computer graphics system as recited in claim 9 wherein the Z raster operations unit further comprises:

a write operation accumulation unit for receiving the merged Z data, and being operative to accumulate portions of merged Z data that are associated with a current tile of merged Z data; and

a compression engine for receiving the accumulated merged Z data, and being operative to compress the accumulated merged Z data to provide compressed Z write data to the memory interface unit to be written to the Z buffer in a compressed format.

17. A computer graphics system as recited in claim 1 further comprising a depth buffer client communicatively coupled with the memory interface unit of the graphics processing unit, the client being operative to generate write requests, write address information, and write Z data to be written to the depth buffer, the memory interface being responsive to the write requests and operative to perform read modify write operations for writing the write Z data to the depth buffer for the client.

18. A computer graphics system as recited in claim 17 wherein the read modify write operations performed by the memory interface unit comprise the steps of:

determining whether a memory location of the depth buffer indicated by the write address information includes a portion of compressed Z data stored therein in a compressed format; and

if the tile region has a compressed portion of Z data stored therein,

reading the compressed portion of Z data from the depth buffer, and

decompressing the compressed portion of Z data

19. A computer graphics system as recited in claim 17 wherein the depth buffer client is a central processing unit executing a graphics application.

20. A computer graphics system as recited in claim 17 wherein the depth buffer client is a 2D graphics engine.

21. A computer graphics system as recited in claim 1 wherein:

the graphics engine is operative to generate memory address values each being indicative of an associated memory address location of the depth buffer; and

the memory interface unit is responsive to the memory address values, and is operative to determine compression status information associated with at least a portion of the memory address values, the compression status information indicating whether an associated portion of Z data stored in the associated memory address location of the depth buffer is stored in a compressed format, or an uncompressed format, the memory interface unit being operative to perform the steps of,

if the compression status information indicates that the associated portion of data is stored in the depth buffer in an uncompressed format, accessing the associated portion of Z data from the depth buffer during a first number of clock cycles, and

if the compression status information indicates that the associated portion of data is stored in the depth buffer in a compressed format, accessing the compressed portion of Z data from the depth buffer during a second number of clock cycles wherein the second number of clock cycles is less than the first number of clock cycles.

22. A computer graphics system as recited in claim 21 wherein the memory interface unit further comprises a tag memory storage unit for storing the compression status information, the tag memory storage unit being responsive to a particular one of the memory address values, and operative to provide the compression status information associated with the particular memory address value.

23. A computer graphics system as recited in claim 2 wherein:

the graphics engine is operative to generate tile memory address values indicative of associated tile regions of the depth buffer, each tile region providing for storage of an associated tile of Z data, each of the tiles of Z data including a plurality of tile portions of Z data, the graphics engine also being operative to generate fetch mask information associated with each of the tile memory address values, the fetch mask information indicating specified ones of the tile portions of the associated tile of Z data, the specified tile portions to be read from the depth buffer; and

the memory interface unit is responsive to the tile memory address values, and the associated fetch mask information, and operative to determine compression status information associated with at least a portion of the memory address values, the compression status information indicating whether the associated tile of Z data is stored at the associated tile region in a compressed format, or in an uncompressed format, the memory interface unit being operative to perform the steps of,

if the compression status information indicates that the associated tile is a compressed tile that is stored in the depth buffer in a compressed format, accessing the compressed format tile using the associated tile memory address value, and

if the compression status information indicates that the associated tile of data is stored in the depth buffer in an uncompressed format, accessing only the specified tile portions of the associated tile of Z data that are specified by the associated fetch mask information.

24. A computer graphics system as recited in claim 4 wherein:

the graphics engine is operative to compress a tile of Z data to generate a compressed tile of Z data including,

a first compressed data portion including a portion of the compressed data, and

fast clear information indicative of whether the compressed tile of Z data represents background initialization Z data for clearing the depth buffer, and if not fast clear compressed, a second compressed data portion; and

the memory interface unit is responsive to the compressed tile of Z data, and operative to read the fast clear information, and further operative to perform the steps of,

if the fast clear information indicates that the compressed tile represents initialization Z data, writing only the first compressed data portion to the depth buffer, and

if the fast clear information does not indicate that the compressed tile represents initialization Z data, writing the first and second compressed data portions to the depth buffer.

25. A graphics processing unit for processing image data including Z data for use in displaying three dimensional images, the graphics processing unit being adapted for coupling with a depth buffer via a depth buffer interface, the depth buffer providing for temporary storage of Z data, the graphics processing unit being operative to compress at least a portion of the Z data, to write the compressed portion of Z data to the depth buffer via the depth buffer interface in a compressed format, to read portions of compressed Z data from the depth buffer via the depth buffer interface, and to decompress the compressed Z data read from the depth buffer, whereby effective Z data bandwidth through the depth buffer interface is maximized in order to facilitate fast depth buffer access operations.

26. A graphics processing unit as recited in claim 25 further comprising

a graphics engine for generating image data including Z data; and

a memory interface unit communicatively coupled to the graphics engine and being adapted for communicative coupling with a depth buffer via a depth buffer interface.

27. A graphics processing unit as recited in claim 26 being further operative to compress selected ones of a plurality of tiles of the generated Z data based on a quantitative analysis of the Z data, each of the tiles of Z data having a plurality of pixels arranged in an array, each of the pixels being disposed at an associated (X,Y) coordinate of the array, and having an associated Z value.

28. A graphics processing unit as recited in claim 27 being further operative to perform a process of compressing a tile of Z data, the process including a step of determining a plane based on the (X,Y) coordinates and associated Z values of selected ones of the pixels of the tile.

29. A graphics processing unit as recited in claim 27 being further operative to perform a process of compressing a tile of Z data, the process comprising the steps of:

reading an anchor Z value associated with a selected anchor pixel of the tile;

reading a major horizontal Z value associated with a major horizontal pixel displaced a first predetermined number of pixels in a horizontal direction from the anchor pixel;

determining a major horizontal difference value between the anchor Z value and the major horizontal Z value;

determining a horizontal gradient value based on the horizontal difference value and the first predetermined number of pixels;

reading a major vertical Z value associated with a major vertical pixel displaced a second predetermined number of pixels in a vertical direction from the anchor pixel;

determining a major vertical difference value between the anchor Z value and the major vertical Z value;

determining a vertical gradient value based on the vertical difference value and the second predetermined number of pixels;

determining an ideal plane based on the anchor Z value, the horizontal gradient value, and the vertical gradient value;

for each of a plurality of remaining pixels of the tile, determining an associated ideal Z value lying in the ideal plane at the (X,Y) coordinate of the associated remaining pixel; and

for each of the remaining pixels, determining an associated minor Z difference value by determining a difference between the associated ideal Z value and the associated Z value.

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30. A graphics processing unit as recited in claim 26 wherein the graphics engine comprises:

a plurality of graphics pipeline stages for generating image data including Z data; and

a Z raster operations unit communicatively coupled with the memory interface unit, the Z raster operations unit for receiving the generated Z data, and being operative to compress selected portions of the generated Z data, to receive compressed Z data from the depth buffer via the memory unit interface and the depth buffer interface, and to decompress the compressed Z data.

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31. A graphics processing unit as recited in claim 26 wherein the Z raster operations unit is operative to perform read modify write operations including the steps of:

reading previous Z data from the depth buffer via the memory unit interface and the depth buffer interface;

merging the previous read Z data with associated portions of the generated Z data to provide merged Z data; and

writing the merged Z data to the depth buffer via the memory unit interface and the depth buffer interface.

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32. A graphics processing unit as recited in claim 26 wherein the Z raster operations unit is operative to perform read modify write operations including the steps of:

reading previous compressed Z data from the depth buffer via the memory unit interface and the depth buffer interface;

decompressing the read Z data;

merging the decompressed read Z data with associated portions of the generated Z data to provide merged Z data; and

writing the merged Z data to the depth buffer via the memory unit interface and the depth buffer interface.

33. A graphics processing unit as recited in claim 31 wherein the read modify write operations further include the steps of:

compressing the merged Z data; and

writing the merged Z data to the depth buffer via the memory unit interface and the depth buffer interface in a compressed format.

34. A graphics processing unit as recited in claim 32 wherein the read modify write operations further include the steps of:

compressing the merged Z data; and

writing the merged Z data to the depth buffer via the memory unit interface and the depth buffer interface in a compressed format.

35. A graphics processing unit as recited in claim 27 wherein the Z raster operations unit is operative to perform read modify write operations including the steps of:

reading a tile of previous Z data from the depth buffer via the memory unit interface and the depth buffer interface;

merging the previous read Z data with associated portions of the generated Z data to provide a tile of merged Z data;

determining if the tile of merged Z data may be compressed; and

if the merged Z data may be compressed, writing the tile of merged Z data to the depth buffer via the memory unit interface and the depth buffer interface in a compressed format.

36. A graphics processing unit as recited in claim 27 wherein the Z raster operations unit comprises:

a read operation data accumulation unit for receiving the generated Z data, and being operative to accumulate portions of generated Z data associated with a current tile region, and to provide the accumulated Z data;

a decompression engine for receiving a previously written compressed tile of read Z data that is read from the Z buffer via the memory interface unit in a compressed format, the decompression engine being operative to decompress the previously written compressed tile to provide decompressed read Z data; and

a test unit for receiving the accumulated Z data and the decompressed read Z data, and being operative to compare portions of the accumulated Z data with portions of the decompressed read data, and being operative to provide selected Z data.

37. A graphics processing unit as recited in claim 26 wherein the Z raster operations unit further comprises:

a write operation accumulation unit for receiving the merged Z data, and being operative to accumulate portions of merged Z data that are associated with a current tile of merged Z data; and

a compression engine for receiving the accumulated merged Z data, and being operative to compress the accumulated merged Z data to provide compressed Z write data to the memory interface unit to be written to the Z buffer in a compressed format.

38. A graphics processing unit as recited in claim 26 wherein:

the graphics engine is operative to generate memory address values each being indicative of an associated memory address location of the depth buffer; and

the memory interface unit is responsive to the memory address values, and is operative to determine compression status information associated with at least a portion of the memory address values, the compression status information indicating whether an associated portion of Z data stored in the associated memory address location of the depth buffer is stored in a compressed format, or an uncompressed format, the memory interface unit being operative to perform the steps of,

if the compression status information indicates that the associated portion of data is stored in the depth buffer in an uncompressed format, accessing the associated portion of Z data from the depth buffer during a first number of clock cycles, and

if the compression status information indicates that the associated portion of data is stored in the depth buffer in a compressed format, accessing the compressed portion of Z data from the depth buffer during a second number of clock cycles wherein the second number of clock cycles is less than the first number of clock cycles.

39. A graphics processing unit as recited in claim 26 wherein the memory interface unit further comprises a tag memory storage unit for storing the compression status information, the tag memory storage unit being responsive to a particular one of the memory address values, and operative to provide the compression status information associated with the particular memory address value.

40. A graphics processing unit as recited in claim 27 wherein:

the graphics engine is operative to generate tile memory address values indicative of associated tile regions of the depth buffer, each tile region providing for storage of an associated tile of Z data, each of the tiles of Z data including a plurality of tile portions of Z data, the graphics engine also being operative to generate fetch mask information associated with each of the tile memory address values, the fetch mask information indicating specified ones of the tile portions of the associated tile of Z data, the specified tile portions to be read from the depth buffer; and

the memory interface unit is responsive to the tile memory address values, and the associated fetch mask information, and operative to determine compression status information associated with at least a portion of the memory address values, the compression status information indicating whether the associated tile of Z data is stored at the associated tile region in a compressed format, or in an uncompressed format, the memory interface unit being operative to perform the steps of:

if the compression status information indicates that the associated tile is a compressed tile that is stored in the depth buffer in a compressed format, accessing the compressed format tile using the associated tile memory address value, and

if the compression status information indicates that the associated tile of data is stored in the depth buffer in an uncompressed format, accessing only the specified tile portions of the associated tile of Z data that are specified by the associated fetch mask information.

41. A graphics processing unit as recited in claim 27 wherein:

the graphics engine is operative to compress a tile of Z data to generate a compressed tile of Z data including,

a first compressed data portion including a portion of the compressed data, and fast clear information indicative of whether the compressed tile of Z data represents background initialization Z data for clearing the depth buffer, and if not fast clear compressed, a second compressed data portion; and

the memory interface unit is responsive to the compressed tile of Z data, and operative to read the fast clear information, and further operative to perform the steps of,

if the fast clear information indicates that the compressed tile represents initialization Z data, writing only the first compressed data portion to the depth buffer, and

if the fast clear information does not indicate that the compressed tile represents initialization Z data, writing the first and second compressed data portions to the depth buffer.

42. A process of managing and accessing Z data in a computer graphics system including a graphics processing unit for generating image data including Z data, and a depth buffer communicatively coupled with the graphics processing unit via a depth buffer interface, the depth buffer providing for temporary storage of the data, comprising the steps of:

compressing at least a portion of the generated Z data;

writing the compressed portion of Z data to the depth buffer via the depth buffer interface in a compressed format;

reading portions of compressed Z data from the depth buffer via the depth buffer interface; and

decompressing the compressed Z data read from the buffer;

whereby effective Z data bandwidth through the depth buffer interface is maximized in order to facilitate fast depth buffer access operations.

43. A process as recited in claim 42 wherein the step of compressing at least a portion of the generated Z data comprises compressing selected ones of a plurality of tiles of the generated Z data based on a quantitative analysis of the Z data, each of the tiles of Z data having a plurality of pixels arranged in an array, each of the pixels being disposed at an associated (X,Y) coordinate of the array, and having an associated Z value.

44. A process as recited in claim 43 wherein the step of compressing further comprises a step of determining a plane based on the (X,Y) coordinates and associated Z values of selected ones of the pixels of the tile.

45. A process as recited in claim 43 wherein the step of compressing further comprises the steps of:

reading an anchor Z value associated with a selected anchor pixel of the tile;

reading a major horizontal Z value associated with a major horizontal pixel displaced a first predetermined number of pixels in a horizontal direction from the anchor pixel;

determining a major horizontal difference value between the anchor Z value and the major horizontal Z value;

determining a horizontal gradient value based on the horizontal difference value and the first predetermined number of pixels;

reading a major vertical Z value associated with a major vertical pixel displaced a second predetermined number of pixels in a vertical direction from the anchor pixel;

determining a major vertical difference value between the anchor Z value and the major vertical Z value;

determining a vertical gradient value based on the vertical difference value and the second predetermined number of pixels;

determining an ideal plane based on the anchor Z value, the horizontal gradient value, and the vertical gradient value;

for each of a plurality of remaining pixels of the tile, determining an associated ideal Z value lying in the ideal plane at the (X,Y) coordinate of the associated remaining pixel; and

for each of the remaining pixels, determining an associated minor Z difference value by determining a difference between the associated ideal Z value and the associated Z value.

46. A process as recited in claim 45 wherein the process further comprises the steps of:

using the major horizontal difference value as a first major difference value in the compressed format;

using the major vertical difference value as a second major difference value in the compressed format; and

using the minor Z difference values as minor difference values in the compressed format.

47. A process as recited in claim 45 wherein a compressed tile of Z data comprises:

a first portion of compressed Z data including the anchor Z value, the major vertical difference value, and the major horizontal difference value; and

a second portion of compressed Z data including at least one of the minor difference values.

48. A process as recited in claim 45 wherein the graphics processing unit is further operative to perform the steps of:

determining if the horizontal difference value is greater than a predetermined maximum value; and

if the horizontal difference value is greater than the predetermined maximum value, writing the tile of Z data to the depth buffer via the depth buffer interface in an uncompressed format.

49. A process as recited in claim 45 wherein the graphics processing unit is further operative to perform the steps of:

determining if the vertical difference value is greater than a predetermined maximum value; and

if the vertical difference value is greater than the predetermined maximum value, writing the tile of Z data to the depth buffer via the depth buffer interface in an uncompressed format.

50. A process as recited in claim 45 wherein the graphics processing unit is further operative to perform the steps of:

determining if any of the associated minor Z difference values is greater than a predetermined maximum value; and

if any of the minor Z difference values is greater than a predetermined maximum value, writing the tile of Z data to the depth buffer via the depth buffer interface in an uncompressed format.

51. A process as recited in claim 45 wherein the graphics processing unit is further operative to perform the steps of:

determining if any of the associated minor Z difference values is greater than a predetermined maximum value; and

if any of the minor Z difference values is greater than a predetermined maximum value, writing the tile of Z data to the depth buffer via the depth buffer interface in an uncompressed format.

52. A computer graphics system for processing image data including Z data for use in displaying three dimensional images on a display unit, comprising:

a depth buffer providing for temporary storage of Z data; and

a graphics processing unit having a graphics engine for generating image data including Z data, and a memory interface unit communicatively coupled to the graphics engine and communicatively coupled to the depth buffer via a depth buffer interface, the graphics processing unit being operative to determine if at least a portion of the generated Z data is compressible, to compress the portion of the generated Z data and to write the compressed portion of Z data to the depth buffer via the depth buffer interface in a compressed format if it is compressible, to write the portion of Z data to the depth buffer via the depth buffer interface in an uncompressed format if it is not compressible, to read portions of compressed Z data from the depth buffer via the depth buffer interface, and to decompress the compressed Z data read from the buffer;

whereby effective Z data bandwidth through the depth buffer interface is maximized in order to facilitate fast depth buffer access operations.

53. A computer graphics system as recited in claim 52 wherein the graphics processing unit is operative to compress selected ones of a plurality of tiles of the generated Z data based on a

quantitative analysis of the Z data, each of the tiles of Z data having a plurality of pixels arranged in a jittered pattern, each of the pixels being disposed at an associated irregular (X,Y) sample point, and having an associated Z value.

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